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Turbulence Intensity Calculation for Al-Shehabi Site in Iraq

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ABSTRACT: The Turbulence Intensity "TI" is a very important factor in determining the performance and productivity of the wind turbines. Also, the appropriate turbine class for that site depending on the turbulence intensity of the winds in the studied area.To assess the category of a wind turbine at a site, data from an open space area are collected and analyzed. The data were collected from a tower installed at Al-Shehabi site, as the open space. The result for this area is compared with the standard NTM in order to calculate the turbulence intensity atAl-Shehabi site for the year2013; the calculations were achievedusing Computer code for Optimum Wind Farm Design (COWFD).

KEYWORDS: wind energy, ambient turbulence intensity, IEC61400, wind turbine category

I. INTRODUCTION

Wind energy is the most promising energy source which is believed to play an important role in global power supply in the 21stcentury. Wind energy is the least cost type of renewable energy technology, yet it is a huge source and according to the reports from United Nations, the total potential for wind energy alone can satisfy the electricity world demand by 20 times.[1]

In the past few years, the economics of wind energy has improved dramatically in many developed countries, such that it is now the least expensive option among all energy technologies. Wind Energy has developed very fast in the last decade. Compared with traditional energy sources, wind energy has a number of benefits and advantages. Unlike fossil fuels that emit harmful gases and nuclear power that generates radioactive wastes, wind power is a clean and environmentally friendly energy source. Modern wind turbines size and power output were hardly imaginable only a few years ago. Generation of electrical energy from wind can be economically achieved only where a significant wind resource exists.[2]For any wind turbine, the power and energy output increases dramatically as the wind speed increases. Therefore, the most cost effective wind turbines are located in the windiest area. Wind speed is affected by local terrain and increases with height above the ground, so wind turbines are usually mounted in tall towers.[3]

II. METEOROLOGICAL PARAMETER (TURBULENCE INTENSITY)

Turbulence intensity is the standard deviation of the wind speed within a time step divided by the mean wind speed over the same time step. Turbulence intensity (TI) is a measure of the gustiness of the wind. High turbulence is associated with increased wind turbine system wear and increased operation and maintenance (O&M) costs. At lower wind speeds, the calculated turbulence intensity is higher. However, the higher turbulence at low wind speeds is not a concern because of the low power available at those low wind speeds. Turbulence at higher winds speeds is of greater interest and concern to wind turbine.[4]
In wind energy, the turbulence is evaluated by the turbulence intensity. The turbulence intensity is calculated by dividing the standard deviation of a 10 minute wind speed measurement by the mean wind speed:

$$TI_V = {}^{\sigma_V}/_{\bar{V}} \qquad (1)$$

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where σ_V is the standard deviation of wind speed variations about the mean wind speed $\bar{V}$, due to this definition TI_V can become infinitely large when the wind speed reaches zero.
According to IEC61400-1 edition 2, NTM for small wind turbine states that the expected standard deviation of longitudinal wind σ1, should be given by [2]:

$$\sigma_1 = \frac{I_{15}(15m/sec + aV_{hub})}{a+1} + \Delta\sigma_1 (2)$$

where, I_{15} =is the assumed turbulence intensity at a mean wind speed of 15m/s.
a= is a slope parameter.
V_{hub} = is the wind speed at hub height averaged over 10min, see Table 1.

These parameters have a constant value of I_{15} =18% and 16% for class A and B respectively, where
a =2 for class A.
a=3 for class B (see Table1).
The term $\Delta\sigma_1$ in Eq. (2) is a modification which let the model correspond to different percentile values.

$$\Delta\sigma_1 = 2(P-1)\mathrm{I}_{15} \ (3)$$

where,
σ_1 = is the hub-height longitudinal wind velocity standard deviation.
I_{15}= is the characteristic value of hub-height turbulence intensity at a 10 min average wind speed of 15 m/s and a function of turbine class (see Table 1).
p = is determined from the normal probability distribution function which corresponds to *p* = 0 for the 50thpercentile, and *p* = 1.28 for the 90thpercentile, and *p* =1 for the 84thpercentile which defines the characteristic turbulence intensity.

Table 1: IEC 61400-1 1999 Edition 2

WTG Class		I	II	III	IV	S
V_{ave} (m/s)		10	8.5	7.5	6.0	manufacturer
V_{ref} (m/s)		50	42.5	37.5	30.0	
A	I_{15}	0.18	0.18	0.18	0.18	
	a	2	2	2	2	
B	I_{15}	0.16	0.16	0.16	0.16	
	a	3	3	3	3	

The expected 10 minutes mean turbulence intensity, is given by normalizing Eq. (2) over V_{hub}. According to IEC61400-1 edition 3, NTM for large wind turbine states the expected standard deviation $\sigma 1$ is described based on an approximation of the 90thpercentile of the standard deviation of the longitudinal wind speed:[2]

$$\sigma_1(90^{th}) = I_{ref}(0.75V_{hub} + 5.6\,m/\mathrm{sec}) \qquad (4)$$

While the distribution value of the 50thpercentile standard deviation of the large wind turbine, is given as guidance by the following expression.[4]

$$\sigma_1(50^{th}) = I_{ref}(0.75V_{hub} + 3.75\,m/\mathrm{sec})(5)$$

Where, *I*ref= is the representative value of hub-height turbulence intensity at a 10 min average wind speed of 15m/s and a function of turbine class (see Table 2).

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Table 2: IEC 61400-1 2005 Edition 3

WTG Class	I	II	III	S
V_{ave} (m/s)	10	8.5	7.5	manufacturer
V_{ref} (m/s)	50	42.5	37.5	
A I_{ref}	0.16			
B I_{ref}	0.14			
C I_{ref}	0.12			

The expected 10 minutes mean turbulence intensity is given by normalizing σ_{90} and σ_{50}over V_{hub}, as following:[5]

$$I_{90} = \frac{\sigma_{90}}{V_{hub}} (6)$$

$$I_{50} = \frac{\sigma_{50}}{V_{hub}} (7)$$

Here, σ_{50} is bin-average of measured 10min value; $\sigma_{90}$is bin-average of 10min values calculated from σ_{ave} and $\sigma_{\sigma}$by the following equation assuming IEC 61400-1 edition 2:[5]

$$\sigma_{90} = \sigma_{ave} + \sigma_{\sigma} (8)$$

Here, $\sigma_{\sigma}$is 10min standard deviation bin-average values. In IEC 61400-1 edition 3, Eq. (9) represented as:[5]

$$\sigma_{50} = \sigma_{ave} + 1.28\sigma_{\sigma} (9)$$

Ambient turbulence intensity in IEC 61400-1 edition 2 given by the representative value for a set of 10-minute time steps, each bin as the averaged value plus standard deviation of turbulence intensity, as follows:[2]

$$TI_{90} = TI_{ave} + \sigma_{TI} (10)$$

Also, the ambient turbulence intensity in IEC61400-1 edition 3 is the representative turbulence intensity, for a set of 10min time steps, is equal to the 90thpercentile of the turbulence intensity values. Assuming a normal distribution of these values, it represents the mean value plus 1.28 times standard deviations. The mean turbulence intensity is the mean value of all of the turbulence intensity data at a particular wind speed.[2]

$$TI_{84th} = TI_{ave} + 1.28\,\sigma_{TI} (11)$$

III. RESULTS AND DISCUSSIONS

Al-Shehabi was selected as an open space site to study turbulence intensity effects. Fig. 1 shows its position on Iraq map. Data was collected from meteorological station for the year 2013 at 10m above ground level.

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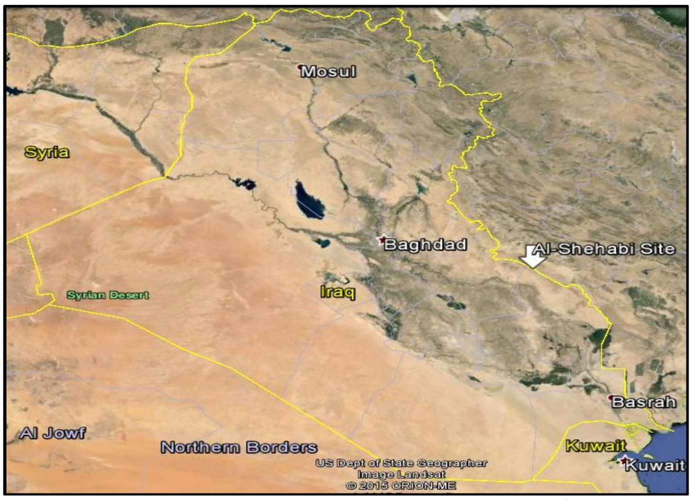

Fig. 1 Iraq satellite image to indicate the area of study

The Fig.2 shows that wind rose divided into 12 sectorsexplained the distribution of frequency, speed and energy in different directions. Wind at this location blowing mostly from the northeastern, and northern directions, in addition to winds blowing from other directions.

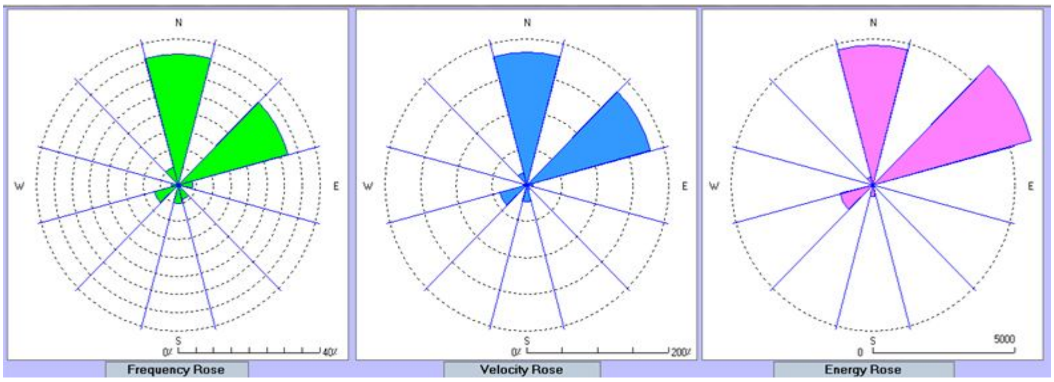

Fig.2 Wind rose diagram for Al-Shehabi 2013, 10m height

The standard deviation of wind speed is plotted as a function of mean wind speed, in both Figs. 3(a)-(b). The red dots represent each of calculated σ_v value. A linear regression is calculated, with the use of the least square method, and drawn as a pink color line through all of the σ_v points.

The calculated standard deviation are compared to the NTM given by Eq.(2), where the orange, black and green lines represents the three turbine classes A, B and C respectively (see Figs.3(3)-(b)), such that the turbine classes in the left graph represent the 90thpercentile, while the turbine classes in the three right graph represent the 50thpercentile

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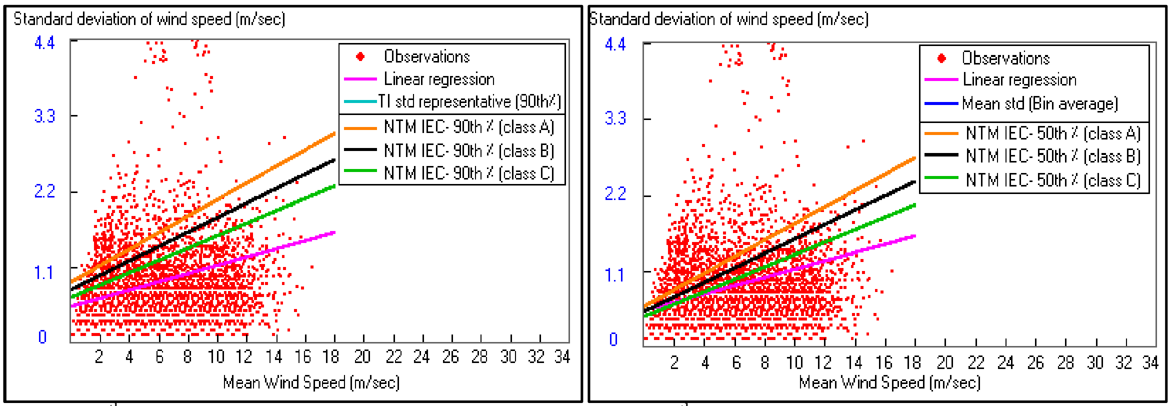
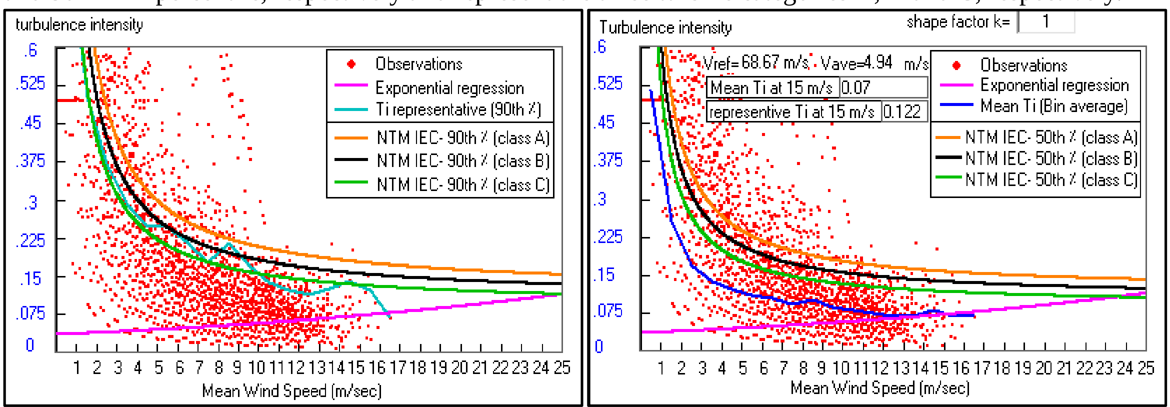


(a)90th% Standard deviation as a function of $\bar{v}$whichbelongs to Al-Shehabisite for LWT- 2013.

(b) 50th% Standard deviation as a function of $\bar{v}$which belongs to Al-Shehabi site for LWT- 2013.

Fig.3 Standard deviation as a function of$\bar{v}$which belongs to Al-Shehabi site for SWT

Figs. 4(a)-(b) show the results of turbulence intensity *TI*given by Eq. (1) in red dots.The calculated mean and representative *TI* (TI_{50} and TI_{90}) by Eqs.(4)-(5), where the orange, green and black lines in Figs. 4(a)–(b) represent the 90thand 50thNTM percentile, respectively and represent the three turbine categories A, B and C, respectively.



(a) 90th%turbulence intensity as a function of $\bar{v}$ which belongsAl-Shehabi site for LWT-2013(b) 50th%turbulence intensity as a function of which belongs toAl-Shehabi site for LWT-2013

Fig. 4 Turbulence intensity as a function of mean wind speed belongs to Al-Shehabi site for large wind turbine

In Fig. 5, the distribution of turbulence intensity, *TIv*, is shown in yellow bars divided into intervals with bin size of 5%. The left y-axis denotes the relative frequency of occurrence of *TIv*within different intervals. The maximum value of x-axes is taken to be (120%)for convenience.

The highest frequency of turbulence intensity is located in the range of (5-10%) with majority of frequency measurements arranged as(5-15%), for the years 2013. The cumulative frequency of turbulence is given on the right y-axis as a total number of elements.

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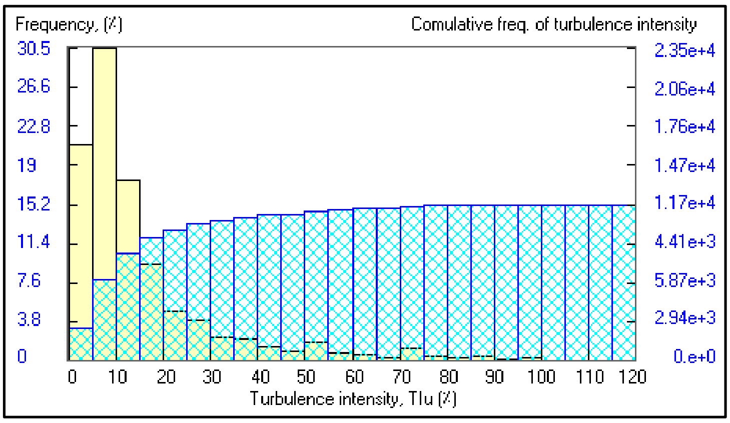

Fig.5 Frequency of turbulence intensity and its cumulative as a function of turbulence intensity which belongs to Al-Shehabi site

The distributions (frequency) of *TI* as a function of mean wind speed can be seen in Fig. 6, representing by green bars binned with intervals of 1m/s. The frequency of turbulence intensity is given on the y-axis as a total number of elements in each wind speed interval. The highest frequency of turbulence intensity occurs at wind speed interval (1-2) m/s with value 24% for 2013.

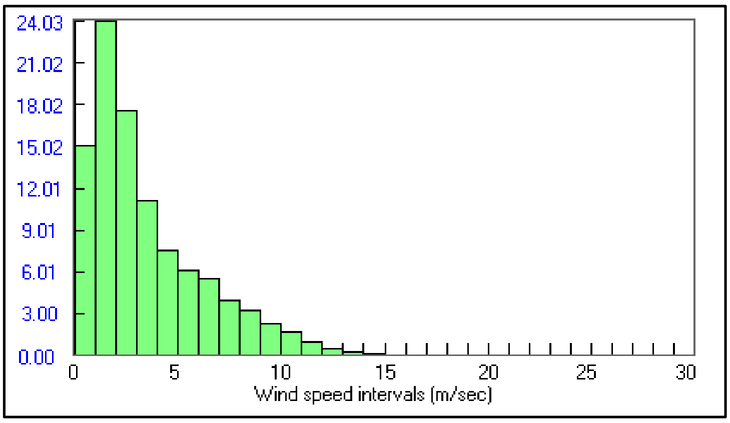

Fig. 6TI as a function of $\bar{v}$ which belongs to Al-Shehabi site

Now, it is possible to find turbulence intensity at each sector, the plots of TI as a function of wind speed in 8 sectors for Al-Shehabi sites are shown in Fig.7.

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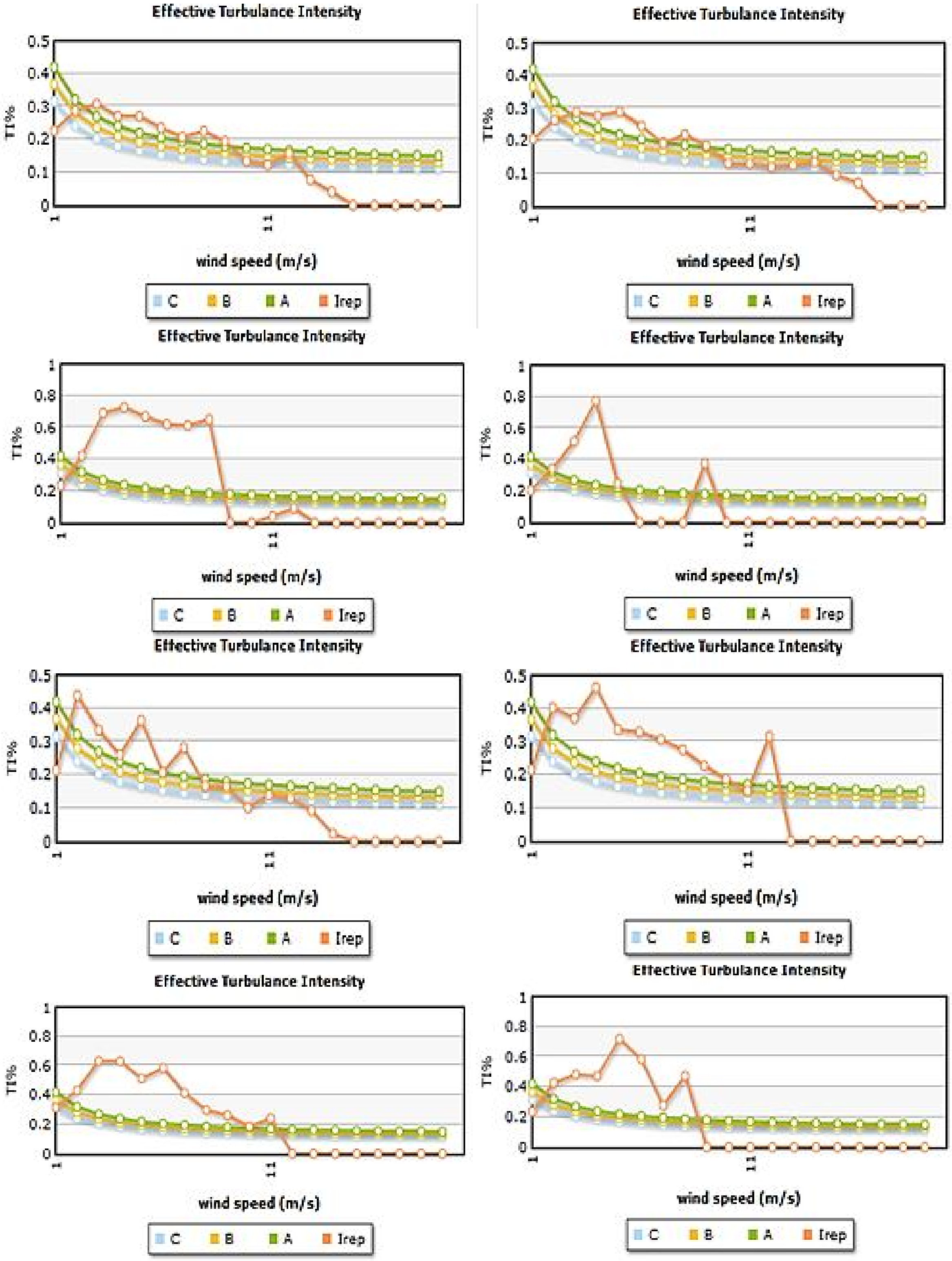

Fig.7 Representative turbulence intensity (*I*rep) at different directions, Al-Shehabi (2013)

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After computing *I*rep-s for each sector as shown in Fig. 7, now it could be possible to compute total*I*rep at wind speed 10m/sec for Al-Shehabi site. As expected from proceeding calculations, the results show that *I*rep for both locations, *I*rep= 0.160978 (see Table 3)

Table 3:*I*rep_s and *I*rep for 8 sectors at wind speed 10m/sec for Al-Shehabi site

Item/ Sector No.	1	2	3	4	5	6	7	8
*I*rep_s%	17.6	16.0	49.0	0.0	18.0	20.3	31.1	0.0
Freq_s%	36.1	31.4	3.5	3.2	4.7	6.5	2.7	3.3
No. of Samples	12712	11056	1247	1138	1668	2303	943	1149
*I*rep_total=	0.1609							

The power curve measurement at a test site must include a measure of the turbulence level to permit a possible correction to the power curve. The effects of turbulence on wind turbine power curves are estimated in Fig.8. It is obvious that there is no change in the theoretical power curves of the two sites, because turbulence intensity at these sites is not high enough to make change in the theoretical power curves.

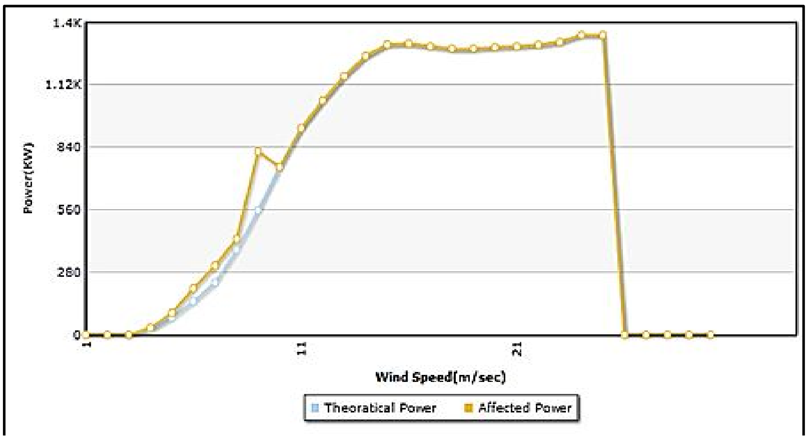

Fig. 8 Effect of turbulence intensity on power curve at two sites

IV. CONCLUSION

The observations from Al-Shehabi site show that the turbulence characteristics of terrain has no deviation from what is estimated by the NTM, as it is defined for the standard LWT and SWT classes, and that is beyond the roughness of the site. Turbulence makes no changes to the output power from a wind turbine, at the same time increases fatigue load and little periodic maintenance, which has no effect on the turbine life and no increasing makes no turbine total cost.

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BIOGRAPHY

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